Validation of Spectral IOP and Particle Characteristics

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LONG-TERM GOALS

Providing particle characteristics such as particle size distribution (PSD) and particle composition (n_p) from ocean color data greatly facilitates classifying water types and predicting optical properties of natural waters. This information impacts many Navy warfare areas which depend on active and passive imagery or that require knowledge of particle types and their dispersion. Potential methods to predict particle characteristics using the inherent optical properties (IOPs) has been proposed (Boss et al. 2001; Twardowski et al. 2001). Haltrin and Arnone (2003) put forward an algorithm to separate particle type into large and small particles and terrigenic versus organic source and concentration of particles using remote sensing data using spectral particulate coefficient information. This work however relied heavily on assumptions between the backscattering to scattering ratio and the ability to iterate using scattering efficiencies to derive total particle number given a Junge slope via Twardowski et al. The ultimate goal of the work reported here is to examine these algorithms and their assumptions in order to provide more confidence in the methods used to retrieve in-situ particle and optical properties from either passive or active remote sensing and from either underwater, airborne, or satellite platforms. Knowing the optical and particle properties of the water can improve the predicted performance of active and passive imaging systems and our ability to differentiate possible biological threats in an area. It is the goal of this research to strive to produce such data that will aid in the characterization of the battlespace environment for electro-optical systems deployed by the Navy for Mine Counter Measures, Naval Special Warfare, Intelligence Surveillance and Reconnaissance, and Anti-Submarine Warfare.

OBJECTIVES

To improve our estimates of coastal optical properties from remote sensing such a capability should take advantage of the influence of the PSD and bulk n_p on the inherent optical properties (IOPs) of the water column. The objective of this effort is to determine the variability in the relationship between measured IOPs and various measured particle characteristics for lake and coastal waters.   In order to use relationships such as those of Boss et al. (2001) and Twardowski et al. (2001) there must be confidence in the Junge functions description of coastal environments and the impact of composition

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on scattering and attenuation. The objectives for this effort are: 1) to determine the robustness of existing models to predict optical and particle characteristics, 2) determine whether models that estimate refractive index and shape properties can be used with particle concentration to derive observed in-situ optical properties (scattering and backscattering), and 3) identify where present models should be adjusted to better retrieve particle characteristics. The work will include attempts of closure between particle size distribution, particle composition, calculated backscattering and total scattering, and measurements of the volume scattering function. The measured volume scattering function for various water types are necessary to evaluate disparities in using remote sensing reflectances to retrieve optical properties.

APPROACH

The New York Finger Lakes are used as a test area in order to cover a wide dynamic range of inherent optical properties, particle characteristics, and possible remote sensing differences. These lakes range from meso-oligotrophic to hyper-eutrophic and from chlorophyll dominated to inorganic mineral dominated particle types. The main approach is to measure the particle characteristics and the in-situ optical properties for these various water types. Lakes were chosen since being enclosed they can be largely constrained and represent numerous particle types due to fluvial input, plankton diversity, and varying concentrations of organic and minerogenic particles. Even with these diverse characteristics they are for the most part stable over sampling intervals. Lakes are largely impacted by "episodic" events and unlike coastal oceans the physical forcing is mostly point source inputs, stratification, and surface mixed layers.

Lake sampling was conducted from 27 July to 4 August 2005 during a period when the Finger Lakes are dominated by different particle types (inorganic $CaCO_3$, phytoplankton (diatoms versus bluegreen), and clay). The lakes include Onondaga Lake, Otisco Lake, Owasco Lake, Skaneateles Lake, Seneca River, and Cross Lake. Seneca River stations represent areas where phytoplankton changes and particle characteristics (inorganic and organic) change rapidly due to zebra mussel presence with high scattering b (b(650)>7 m^{-1}). In contrast Skaneateles is a low production lake dominated by phytoplankton with little inorganic and low scattering (b(650)<0.5 m^{-1}). The optical measurements include 1) laboratory spectral absorption, (absorption by detritus, CDOM, and phytoplankton), 2) in-situ spectral total absorption, filtered absorption, and total attenuation (Wetlabs Inc. acs), 3) in-situ spectral scattering measurements at selected angles (WetLabs Inc ECO-VSF, and 9-channel backscattering sensor), 4) in-water spectral downwelling irradiance and upwelling radiance (Satlantic Inc., Hyperpro), 5) laboratory measurements of the volume scattering function at 8 wavelengths (MVSM, NRLSSC), and 6) laboratory and in-situ particle size distribution, and laboratory measurements of chemical composition. Except for Onondaga Lake, samples were taken at the surface, for Onondaga Lake samples were collected at the surface and also near the bottom (8 m).

Particle characterization was carried out on bulk samples in-situ and on laboratory samples. Particle properties measured include the particle size distribution (Sequoia Scientific LISST), total and volatile suspended sediment concentrations, and chemical constituents of the particles. Properties of the particles include measurements of the particle size distribution, inorganic and organic suspended material, and the chemical composition and a shape index. The chemical composition of surface samples that were measured with the MVSM were also analyzed using a Scanning Electron Microscope modified with an X-ray energy spectrometer (SAX). This instrument provides particle size, shape index, and chemical composition (but has been demonstrating some bias with respect to inorganic and organic particles). The chemical composition information is being used with particle

size data to estimate the bulk relative refractive index of the sample as well as the scattering and backscattering via Mie theory. The particle size distribution (PSD) was measured with the SAX and then the slope derived over the 1.25 um and higher range fitting to the Junge functional form. This was necessary due to the "non-Junge-like" distribution as will be presented below. The spectral slope of the attenuation coefficient as discussed in Boss et al. (2001) and Twardowski et al. (2001) is compared with the particle size distribution slope. The results are then used to help interpret data collected using the MVSM in the backward direction.

WORK COMPLETED

Water samples have been collected from ten locations in New York; 1) Owasco Lake, 2) Skaneateles Lake, 3) Otisco Lake (North basin) 4) Otisco Lake (South basin), 5) Onondaga Lake (1 and 8 meter depths), 6) Seneca River Buoy 424, 7) Cross Lake (North area), 8) Cross Lake (South area), 9) Seneca River Buoy 409, and 10) Seneca River Buoy B317. For each station laboratory measurements of particulate and dissolved absorption using a spectrometer, as well as, particle size, asphericity index, and chemical composition using the SAX have been made. MVSM scattering function was measured at nearly all the sites. In-situ data collected includes the total attenuation, particulate absorption, dissolved absorption, particle size distribution (via LISST), and spectral backscattering. In these turbid waters (c ranging from <1 to > 8 m^{-1}) there was uncertainty in values of "b". To help resolve this a comparison between laboratory (filter pad, and dissolved) and field measured (Wetlabs acs with and without filter) absorption was conducted. While some variance was present in the blue end of the spectra, overall this gave confidence to the SAX and spectral c_p comparison. In addition measurements of the volume scattering function (MVSM) were made since multiple scattering issues have been previously suggested in this instrument but such effects are likely in the other in-situ instrumentation as well.

RESULTS

A large range in optical conditions was observed; which was a primary reason for the selection of the Finger Lakes and Seneca River for some of the inherent optical property and particle characteristics investigation. Figure 1 shows that particulate attenuation at 550 nm ranges from 0.52 in Skaneateles to 9.0 in Seneca River. Within the Seneca River stations there was an eightfold difference between the stations impacted by the zebra mussels. There is also clear evidence in figure 1 of the difference in particle types as demonstrated by the slope in the particulate attenuation and the SAX chemical analysis. SAX data showed clay to be the largest single component of the minerogenic fraction in all of the sites reaching over 70% at the buoy station 424 on Seneca River. Calcium Carbonate was a dominate contributor in Otisco Lake, while diatoms dominated much of the projected area per unit volume of high refractive index material in Skaneateles.

Twardowski (2001) and others have suggested that the slope of the particulate attenuation can be used to describe the particle size distribution. As figure 1 demonstrates a large variability in this slope is present in these test areas. Figure 2 represents an analysis of particle size distributions for these various water bodies over the range of 0.2 to 30 μm; the best operating range for the SAX instrumentation. Some loss of organic contributions is expected with the SAX but the overall particle size distribution (PSD) is not expected to change significantly in these waters. Note that these waters do not follow Junge type distribution but rather the 2 component shape of Risovic (1993). In order to best compare the spectral cp slope and the PSD slopes, a Junge type distribution was fit over the region of 2 to 30 μm. This still left the slope of the PSD below a value of 3 (range of 2.5 to 2.9 for these

stations) and outside the normal oceanographic range. This is not surprising given the non-Junge like nature of the PSD from the SAX.
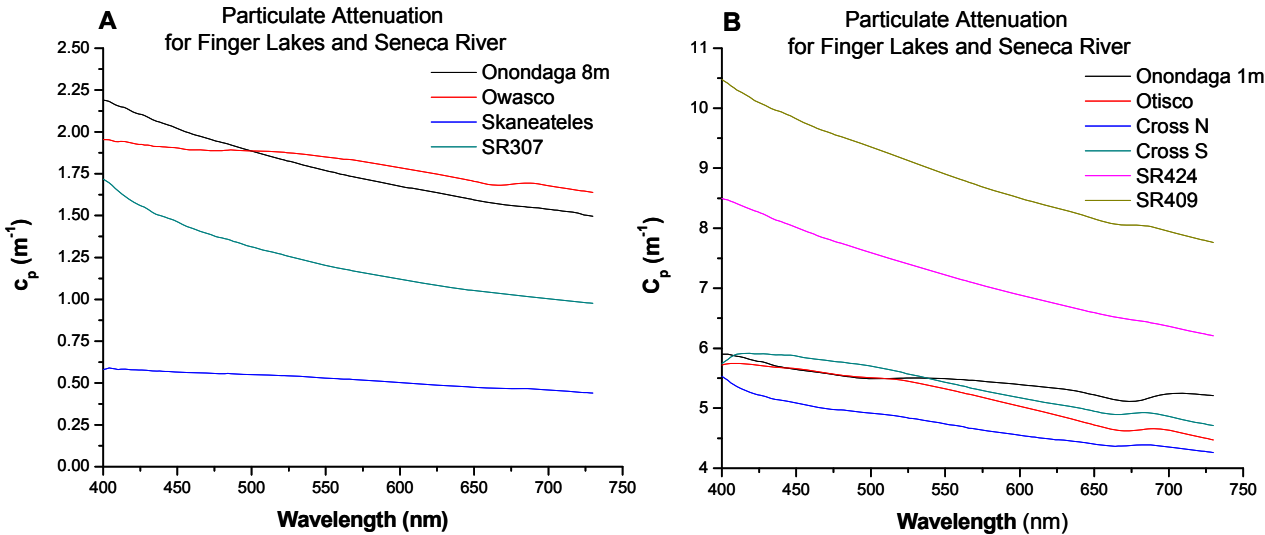

Figure 1. Particulate attenuation for each study site [graph: ac-s derived particle attenuation data showing changing slope in particulate attenuation, panel A representing the low attenuation waters (note very low slope for Skaneateles Lake) and panel B the higher attenuating waters]
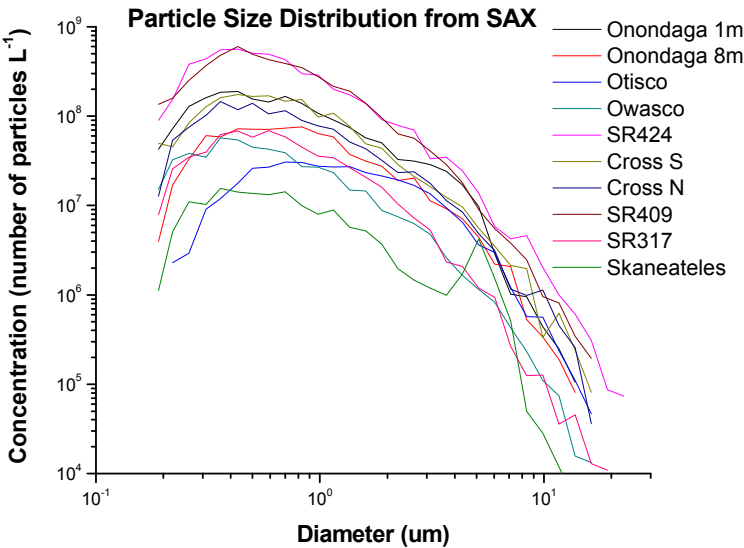

Figure 2. Particle size distribution from SAX [graph: the particle size distribution over range of 0.2 to 30 μm for each sample showing a non-Junge functionality with a peak in the particle size at about 4 to 5 μm]

To determine the ability of the SAX to retrieve the backscattering and scattering coefficient the particle size distribution and the separation of inorganic and minerogenic particles was used. From the chemical composition a bulk relative refractive index was calculated. These values compared well with those determined using particulate backscattering to total scattering ratios from the in-situ data. The range of values was from 1.07 for Skaneateles (phytoplankton dominated) to 1.16 in Otisco North where calcium carbonate persisted. Most other stations were about 1.14 to 1.15. In contrast using the backscattering to total scattering ratio the minimum refractive index was 1.10 for Skaneateles increasing to 1.19 in the Seneca River.
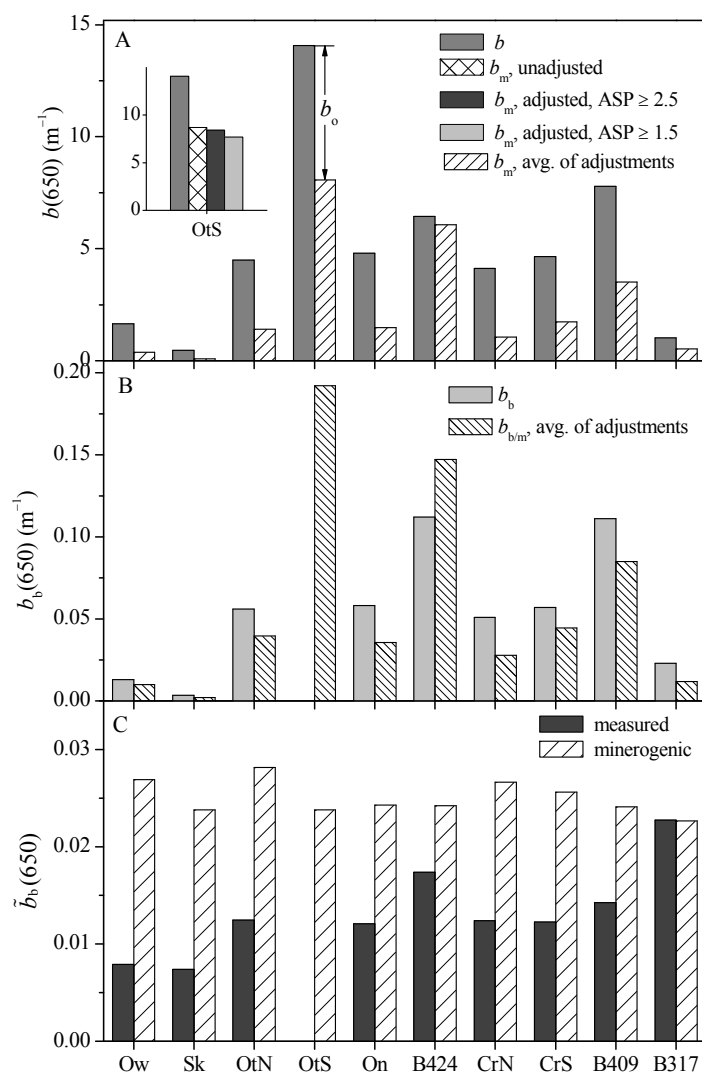

Figure 3. Comparison of scattering and backscattering at 650 nm measured in situ versus that calculated from particle characteristics for minerogenic fraction for a series of New York Finger Lakes [graphs: measured particle scattering b and backscattering b_{bp} versus that calculated from SAX based on Mie Theory using SAX size and chemical composition, panel (A) measured b and SAX b_m with inset showing adjustments to scattering based on asphericity factor (ASP), (B) measured b_{bp}, and b_{bm} by SAX with average asphericity factor, and panel (C) b_{bp}/b_p measured, and b_{bm}/b_m by SAX (m= mineral component, o=organic),]

However the SAX particle size distribution and composition data was also used to calculate the total scattering and backscattering coefficients at 650 nm (Figure 3) via Mie Theory. When this was done the results showed that while the SAX inversion retrieved much of the particulate backscattering, there was a large discrepancy in the total scattering (and therefore the ratio of backscattering to total scattering). An asphericity factor (ASP) was calculated from the SAX data and represents a measure of deviation from a sphere. This did not impact the results of either the scattering or backscattering significantly. For the most part the difference is likely due to the inability of the SAX to properly account for all of the organic fractions whose size classes influenced forward scattering significantly (see panel A). This is expected and also demonstrated in the "SAX-minerogenic" fraction which shows a particulate b_b/b ratio more closely aligned with values expected for highly refractive compounds.

The MVSM measurements often showed a distinct feature in scattering in the backward direction from 140 to 170 degrees (Figure 4). In order to evaluate this change in shape of the scattering function the measurements were normalized to total scattering b, and to scattering at 120 degrees. This was to remove spectral dependencies that were evident in the data as well as give a "hinge" point that is close to that often used in other instrumentation for determining total backscattering.
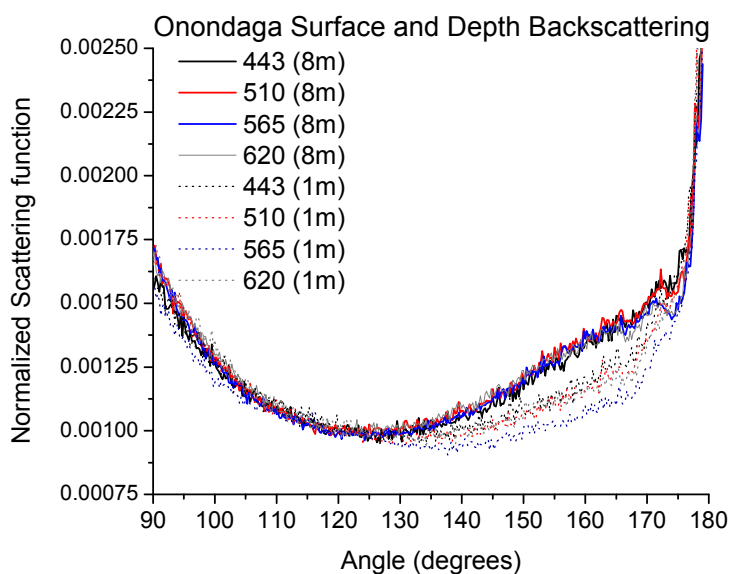

Figure 4. Onondaga surface and 8m backscattering function
[graph: between 130 and 170 degrees there is a marked difference in the normalized
scattering function between the surface and subsurface samples]

This change in the shape of the Volume Scattering Function was thought in previous years to be fully a function of instrument artifacts. However within this past year with careful studies there is now some evidence to suggest that this difference may in fact represent a convolution of instrument sensitivities and actual differences in the shape function. This feature is being addressed more fully.

IMPACT/APPLICATIONS

The impact of the work is that closure between particle optics and bulk optical properties will provide a direct tie to use of remote sensing for characterizing coastal environments. The research also demonstrates how robust the methods used to derive backscattering for various particulate assemblages are in lakes. While seemingly not applicable to marine dynamics, many coastal areas or semi-enclosed basins resemble in their particle types and dynamics. The use of chemical composition and particle properties to evaluate bulk properties will impact how we interpret remote sensing signals, particularly in areas of denied access or for areas where potential contamination is suggested. Lastly for Navy applications the volume scattering variability and the impact of particle types are critical for determining blurring properties that will be used for system performance modeling of Navy imaging systems. If particle types can be deduced from remote sensing, then this information can be utilized for defining biological growth areas, sediment loading, and points of discharge in satellite imagery.

TRANSITIONS

The volume scattering data has been sent to the Canadian Defense Research Development Center (Dr. George Fournier) for application to the LUCIE system for analysis on the impact to blurring on this system of particles with different characteristics; in addition, the non-Junge scattering functions impact on blurring is being evaluated.

The combined particle analysis and lake inherent optical properties is being used by the Upstate Freshwater Institute (Dr. S. Effler) for long-term monitoring of New York Finger Lakes.

RELATED PROJECTS

Improved sensor performance using 'through the sensor' techniques (ONR/NRL 6.2 POC-A. Weidemann)- goal is to derive as much information about the volume scattering function and/or particle types from gated laser system return at multiple distances in order to improve image quality in subsequent images

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Prestigiacomo, T., S. Effler, D. O'Donnell, J. Hassett, E. Michalenko, Z.P. Lee, and A. Weidemann, "*Turbidity and suspended solids levels and loads in a sediment enriched stream and implications for impacted lotic and lentic ecosystems*." Lake and Reservoir Management," (accepted, refereed)

Peng, Feng, S.W. Effler, D. O'Donnell, MG Perkins, Z.P. Lee, and A. Weidemann, "*Minerogenic particles in several lakes and a river is Central New York: Light scattering features from individual particle analysis,*" Limnology and Oceanography (submitted, refereed)